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955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

B71 10018

date: October 26, 1971

to: Distribution

from: C. Bendersky

subject: Technical Status of PPO Foam Internal
Cryogenic Insulation - Case 237

ABSTRACT

The technical status of polyphenyloxide (PPO) foams for use as internal insulation for cryogenic LH_2 tankage is discussed. It is concluded that the material has promise for use in heat sink reusable boosters under study for the Space Shuttle Program, and that the present technology program should be intensified to produce the data necessary for its incorporation in a development program. Areas for additional technology to provide the required data are suggested.

(NASA-CR-125369) TECHNICAL STATUS OF PRO FOAM INTERNAL CRYOGENIC INSULATION (Bellcomm, Inc.) 8 p

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MEMORANDUM FOR FILE

Large size liquid hydrogen propellant tanks are provided with insulation to reduce the heat transfer between the liquid and the environment. Insulation allows the tanks to be filled quickly, reduces hydrogen boil-off during ground-hold and during the boost trajectory. The insulations now in use were designed for expendable boost stages. They are foamed resins installed either on the outside or the inside of the metal tank wall. The SII Stage has external insulation of sprayed-on rigid polyurethane (PU) closed-cell[1] foam while the SIVB stage is internally insulated with PU fiberglass reinforced tiles which are bonded to the milled waffle pattern metal shell.

The reusable mission and life cycle requirements of the Space Shuttle have resulted in new performance requirements for hydrogen tank insulation. For this application, internal insulation has been preferred because exposure to potentially harmful external environments is minimized. Also, the insulation maintains the tank wall and insulation bond line at a relatively even temperature thereby reducing thermal stresses. In the case of the heat sink booster,[2] the concept itself dictates the use of internal insulation to allow the outside tank wall to directly absorb the thermal energy generated during reentry flight. This internal insulation will also control the outside wall temperature during ground hold to a level which will minimize potential tank icing problems[3] prior to launch.

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[1] A closed-cell foam has its outer surface sealed to prevent penetration of either propellant or atmosphere. An open-cell foam permits such penetration.

[2] "Hard Ice Formation on a Heat Sink Booster," Case 237, C. Bendersky, (B71 04034), April 20, 1971.

[3] "Further Comments - Hard Ice Formation on a Heat Sink Booster," Case 237, C. Bendersky, (B71 06034), June 21, 1971.

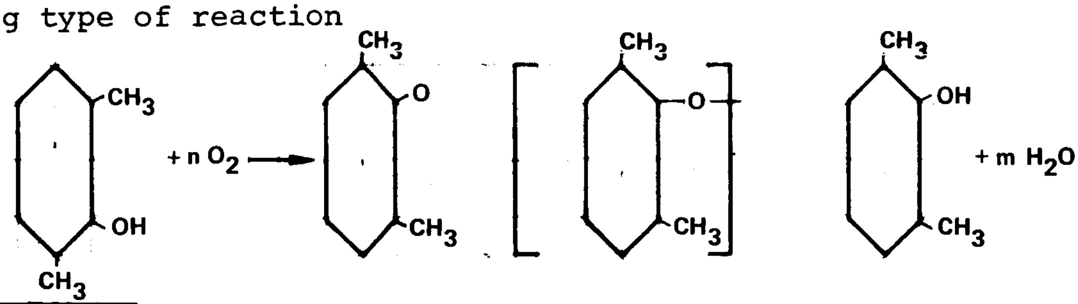
Candidate internal insulation systems with their density and thermal conductivity are listed in Table 1. The polyphenyloxide (PPO) foam is a prime candidate and is particularly favored by Convair Aerospace Division of General Dynamics Corporation (Convair) for comprehensive development because it is open-celled and therefore not subject to cyclic pressure fatigue. It is a simple single-component insulation material; it has the potential for maximum reliability and reusability; it is tough, has good cryogenic properties and a competitive thermal conductivity-density ($k\rho$) product. Convair is conducting a technology program designed to demonstrate the suitability of PPO for the Space Shuttle Booster. Boeing in a recent test program[4] produced evidence that PPO insulation can be pressure sensitive and may sustain permanent damage as a result of repeated pressure cycles. If this were to be verified, then PPO would not be suitable for use on a reusable shuttle.

E. W. Hall (MTG) and this writer visited Convair at San Diego on August 31, and discussed the status of PPO technology with key Convair personnel. Convair feels they can explain the reason for the disappointing results achieved in the Boeing test and they maintain undiminished enthusiasm for the potential of PPO. This writer is impressed with the potential of PPO but believes the present program represents a go no-go approach and that more fundamental technology programs are necessary so as to characterize PPO foam in terms of properties, quality control, and fabrication techniques. The end product of these fundamental programs should be both procurement and performance specifications for both raw stock and fabricated insulation systems.

The remainder of this memorandum provides technical details of PPO and suggested technology tasks.

DISCUSSION

PPO is a polymer of polyphenyloxide conforming to the following type of reaction



[4]"Heat Sink Booster LH_2 Tank Environmental Studies-Analytical and Design Summary," D164-10059-1, The Boeing Company, July 12, 1971.

The basic chemical polymer studies were performed by General Electric in the United States. The material was originally intended for use as a plastic coating similar to Teflon. Later it was considered, in foamed form, as an insulator for use on tankers carrying refrigerated petroleum gas. The market for PPO never materialized. At present PPO is made in Delft, Holland by a company called TNO and is marketed by a Swiss Company called AIREX. PPO foam is an anisotropic, elongated open-cell material which has physical and mechanical properties similar to honeycomb. The foam is manufactured by placing rigid sheets of powdered resin and catalyst between paper covered, steam heated plates and drawing the plates apart rapidly to produce the elongated cellular foam. The outer paper covering is then removed leaving an open-cell sheet or panel. The manufacturing technique results in a density gradient parallel to the fiber direction. In a two inch thick foam slab, the central plane is typically 27 percent less dense than the outer surfaces. The foam cells are sufficiently small to prevent penetration by liquid H_2 but are large enough to be permeated by gaseous hydrogen which is a better insulator than the foam itself.

PPO foam is delivered to Convair in panels roughly 20 x 34 x 2 inches. Approximately 300 panels have been received. X-ray techniques are used to inspect these sheets for internal porosity and high density areas, and approximately 50% of the panels are rejected after inspection. The PPO foam panels have been accurately formed under heat in a vacuum. Shapes have included extremely small radii and elliptical heads. Double curvature bonding and forming of a 29.5 x 18.1 x 1.8 inch panel on a 2024-0 aluminum sheet has been successful. For this, the formed panel was sliced in half, fitted together and then bonded to the Al sheet.

Convair has performed many types of small scale tests to determine the potential reusability of PPO. The critical problem has been the selection of a suitable adhesive. At present a room temperature curing Crest 7343 PU modified with 1-percent Dow-Corning Silane coupling agent (7343Z) appears most promising from a reusability standpoint over a -423 to 300°F temperature range. Three specimens (2 x 12 x 1.8 inch) of PPO foam bonded to 1/8 inch thick 2219 (T-81) aluminum with this agent have been successfully subjected to four hundred load cycles at -423, 70, and 250°F with strains in the aluminum of .0035, .004 and .002 in/in with no observable failures, cracks, or deterioration.

The work thus far completed by Convair may be best described as a successful series of exploratory tests which probed the suitability of PPO foam. Convair is presently under contract to MSC to install PPO in a cylindrical monocoque tank approximately 5-3/4 ft wide and 7 ft high having elliptical heads. Testing will commence during early 1972 and will be designed to demonstrate reusability.

Boeing in Reference 4 described the results of tests conducted in which PPO was repeatedly immersed in liquid H_2. Very little description of the actual test hardware and procedures was provided. Boeing bonded three configurations of PPO foam to a waffle pattern metal wall. The PPO configurations were 3/4", 1-1/4", and 1/2" thick foam with 1/2" thick by 1/2" wide strips bonded to the waffle pattern area. In addition, two thicknesses of PPO were tested to obtain measurements of mean thermal conductivity. Boeing stated that the PPO was pressure sensitive and exhibited minor cracking after several test cycles, but that the cracks did not appear to affect overall performance. The cause of the cracks was not established. Boeing stated that fabrication was extremely difficult when installing the foam over waffle patterns. Curing the PPO was difficult and the (unnamed) resin tended to soak into the insulation causing a heat short in areas where the insulation was thin. However Boeing stated that successful techniques for machining, forming and bonding PPO foam were developed. Nevertheless, Boeing concluded that PPO foam is pressure sensitive and that it might sustain permanent damage as a result of repeated pressure cycles. This conclusion, however, was qualified somewhat by pointing out that the pressure sensitive samples were the small specimens that underwent the thermal conductivity measurement testing. They suggested that materials development, which was not a part of their program, could be desirable. Convair discussed the preceeding results with Boeing in a meeting at MSFC and believes that the pressure sensitivity observed by Boeing resulted from using PPO foam which was both several years old and which had not been inspected for voids and low density. Since Convair presently rejects 50 percent of the foam panels they receive, the critique of the Boeing test procedure may have some merit. Nevertheless the Boeing test results are valid data and are indications that careful quality specifications must be derived for both the foam panels and fabricated insulation systems for use in a high performance reusable Space Shuttle.

COMMENTARY

PPO foam internal insulation systems have high potential for use in cryogenic hydrogen tankage. However the present technology program is limited to an attempt to demonstrate feasibility. Further work should be done with respect to development of satisfactory procurement and fabrication specifications. Convair has made an initial stride in this direction by developing an x-ray inspection technique to qualitatively measure voids and areas of high density of the foam. General areas of research that might prove useful to characterize PPO foam are described below.

1. Basic Chemistry.

The PPO polymer is similar to several used in solid propellant formulations. Additions of small amounts of special chemicals may significantly improve the physical properties over the wide temperature range required for use as an LH_2 insulator. Thus a laboratory polymer program may prove of value.

2. Foam Properties

The equilibrium heat sink wall temperature is a strong function of the equivalent thermal conductivity (k) of the foam. The present method of foam fabrication results in a large density gradient and hence variable k in the direction of heat transfer. Therefore each thickness of the "drawn out" foam results in a different k per unit width. In addition, the present method of drawing results in a variable density throughout the whole panel surface area. It would appear that a materials characterization program is required to establish techniques to control both thickness and porosity and to optimize these factors to maintain a heat sink wall at a desired temperature.

3. Bonding Agents.

The area of metal-to-foam bonding requires further investigation. The room temperature PU modified curing agent used by Convair may prove completely adequate; however adhesive chemistry is a large technological discipline and should be explored in greater depth to obtain the best available adhesive.

4. Quality Control.

The area of inspection techniques must be explored. The large systems which must be installed in shuttle vehicles will be very difficult to inspect and repair. Thus quality control must be stringent to provide the long life required. A program in this area should be designed to provide fabrication procedures and acceptance specifications as well as the actual inspection methods.

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TABLE 1

CRYOGENIC INTERNAL INSULATION SYSTEMS

MATERIAL	THERMAL CONDUCTIVITY K W/M°K (BTU/HR.FT.°R)	DENSITY ρ KG/M^3 (LB./CU.FT.)	$KX\rho$
FIBERGLASS-FILLED HONEYCOMB, PERFORATED FACE SHEET INTERNAL, SST CONCEPT	.0865 (.015)	40 (2.5)	3.46 (0.125)
POLYIMIDE OPEN-CELL FOAM-FILLED HONEYCOMB INTERNAL	.0865 (.050)	40 (2.5)	3.46 (.125)
PPO FOAM INTERNAL	.108 (.0625)	40 (2.5)	4.32 (.156)
POLYURETHANE OPEN-CELL FOAM-FILLED HONEYCOMB INTERNAL	.0865 (.050)	64 (4.0)	5.53 (.200)
POLYURETHANE RIGID CLOSED-CELL FOAM INTERNAL, 3D REINFORCED, S-IVB	.0865 (.050)	88 (5.5)	7.61 (.275)

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